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SLIDING MODE CONTROLLER
POSITION CONTROL DEVICE

FIELD OF THE INVENTION

[0001]   The present invention relates to a control device for positioning a

servomotor or a moving body driven by the servomotor and, in particular relates to a

position control device having a sliding mode controller.

DESCRIPTION OF THE RELATED ART

[0002]   Position control devices for positioning moving bodies such as machine

tool bits often include a Proportional-Integral-Derivative ("PID") controller, which

is designed based on classic control theory. The position of the moving body, or the

position of a servomotor driving the moving body, is detected using a position

detector such as a rotary encoder or a linear scale, and the detected position is

transmitted to a position control device. The difference between a command

position and the detected position is input to a PID controller as an error, and PID

controller gain is altered according to this feedback, adjusting servomotor response.

Proportional gain can be raised to improve process stability, but if the proportional

gain is raised excessively oscillation can occur. Once proportional gain has been

lowered to a level where there is no oscillation, system stability can be further

improved by altering integral gain.

[0003]   Another conventional control theory, known as "sliding mode control

theory," can be used to design controllers which are simple in design, and have

improved controllability characteristics. A sliding mode controller models the state of a control system on a hyperplane by changing gain for determining control input, in accordance with a switching function. Sliding mode control theory has been integrated into control devices for the positioning of moving bodies on machine tools.

[0004]   Figure 1 shows one example of a conventional position control device. The position control device includes sliding mode controller **50** for supplying control input u to control system **10**, disturbance variable compensator **20** for compensating control input u in response to a disturbance, and state observer **30** for observing state variable x. Control system **10** includes a moving body (not illustrated) and a servomotor (not illustrated), and motor torque constant **11** and transfer function **12**. With regard to motor torque constant **11** and transfer function **12**, J represents moment of inertia, s represents a Laplacian operator, and Kt represents a torque constant of a motor. An equation of motion for the control system **10** is expressed by Equation (1):

$$J\ddot{\theta} = Kt \cdot Iq - d \tag{1}$$

[0005]   In Equation (1), θ is the angular position of a servomotor, Iq is q axis current and d is a disturbance value. Based on Equation (1), a state equation representing a function of state variable x, control input u, and controlled variable y can be expressed using the Equation (2).

$$\begin{cases} \dot{x} = A \cdot x + B \cdot u \\ y = C \cdot x \end{cases} \tag{2}$$

$$A = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ Kt/J \end{bmatrix}, C = \begin{bmatrix} 1 & 0 \end{bmatrix}, x = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix}, u = Iq$$

[0006]   With the above-described servo systems, it is critical to identify and eliminate steady state error. Accordingly, an integral value v of error e between a

command position r and a feedback position y which is output from the control

system **10** is given to a switching function σ. In this regard, a state equation to

expand sliding mode control in a servo system is represented below in Equation (3),

and a switching function σ is as shown in Equation (4).

$$\dot{z} = A_s \cdot z + B_s \cdot u + E_s \cdot r + F_s \cdot d \tag{3}$$

$$A_s = \begin{bmatrix} 0 & -C \\ 0 & A \end{bmatrix}, B_s = \begin{bmatrix} 0 \\ B \end{bmatrix}, E_s = \begin{bmatrix} 1 \\ 0 \end{bmatrix}, F_s = \begin{bmatrix} 0 & 1 \end{bmatrix}^T, z = \begin{bmatrix} v \\ x \end{bmatrix}$$

$$\dot{v} = e = r - y$$

$$\sigma = S \cdot z \tag{4}$$

$$S = \begin{bmatrix} S_1 & S_2 & S_3 \end{bmatrix}$$

[0007] The feedback position y is either the measured position θ which is

output from the position detector, or an estimated position output from a suitable

state observer. The error e, which is the difference between a command position r

and a feedback position y, is sent from subtracter **71** to integrator **72**. State

observer **30** receives both a feedback position y and control input u as inputs, and

supplies state variable x to sliding mode controller **50**. State variable x and output

v from the integrator **72** are input to vectorizer 73, and vectorizer 73 outputs a

vector z. The vector z is multiplied by a hyperplane matrix S using multiplier **74**.

[0008] Design and control of a sliding mode controller **50** is governed by

Equation (5):

$$u = u_l + u_{nl} \tag{5}$$

[0009] Here, u_l is a linear control input for causing the state of control system

10 to slide on a switching hyperplane, and u_{nl} is a non-linear control input for

causing the state of control system **10** to face towards the switching hyperplane.

The linear control input u_l is expressed by Equation (6), and the non-linear control

input u_{nl} is represented by Equation (7):

$$u_l = -(S \cdot B_s)^{-1}(S \cdot A_s \cdot z + S \cdot E_s \cdot r) \tag{6}$$

$$u_{nl} = -k(S \cdot B_s)^{-1} \frac{\sigma}{|\sigma| + \eta} \tag{7}$$

[0010] With regard to machine tools that move at high speeds, typically feed

forward compensation of velocity and acceleration is carried out in order to increase

tracking during movement. In these specific cases, switching function σ is

expressed by Equation (8), and the linear control input u_l is expressed by Equation

(9):

$$\sigma = S \cdot z + C_{ff} \cdot r + A_{ff} \cdot \dot{r} \tag{8}$$

$$u_l = -(S \cdot B_s)^{-1}(S \cdot A_s \cdot z + S \cdot E_s \cdot r + C_{ff} \cdot \dot{r} + A_{ff} \cdot \ddot{r}) \tag{9}$$

[0011] With the position control device illustrated in Figure 1, differentiator 46

for differentiating a command position r generates a command velocity $\dot{r}$, and a

differentiator 47 for differentiating command velocity $\dot{r}$ generates command

acceleration $\ddot{r}$. Feedforward compensator 61 amplifies command velocity r using

gain A_{ff}, and feedforward compensator 62 amplifies command position r using

gain C_{ff}. The output $S \cdot z$ of multiplier 74, and the outputs of feedforward

compensator 61 and feedforward compensator 62 are supplied to adder 75, and a

switching function σ is transmitted from adder 75 to smoothing function 76. Block

77 is input with the output from smoothing function 76, and block 77 sends a non-

linear control input u_{nl} to adder 78 based on Equation (7). Feedforward

compensator 51 amplifies command acceleration $\ddot{r}$ using gain A_{ff}, and feedforward

compensator **52** amplifies command velocity $\dot{r}$ using gain C_{ff}. Outputs of

feedforward compensator **51** and feedforward compensator **52** are respectively

transmitted to block **53** and block **54**, and command position r and a vector z are

respectively transmitted sent to block **55** and block **56**. Linear control input u_l is

generated as an output of block **53**, block **54**, block **55** and block **56** based on

Equation (9). Adder **78** generates a control input u, namely q axis current Iq,

which is the output of sliding mode controller **50**. Sliding mode controller **50**

controls the state of a control system **10** on a switching hyperplane by altering

control input u.

[0012]   In order for a servomotor to adequately track a commanded input while

moving, gain in the sliding mode controller **50** must adjusted to match the

parameters of the servo system. If element S_1 in block **74**, corresponding to gain of

an integral value v, is raised, an unwanted overshoot may arise, in response to

stepping.

SUMMARY OF THE INVENTION

[0013]   It is an object of the present invention to address disadvantages found in

prior art position control systems, particularly with regard to those disadvantages

which relate to the prevention of overshoot, without impairing tracking during

movement.

[0014]   According to the present invention, a position control device for causing

a position of a control system, including a servomotor and a moving body driven by

the servomotor, to track a command value, includes a sliding mode controller for

receiving a command position and state variables of the control system, according to

Equation (10), and for providing a control input to the servomotor.

$$x = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix} \qquad (10)$$

[0015]   In Equation (10), θ is a feedback position and $\dot{\theta}$ is feedback velocity. The position control device also includes a disturbance variable compensator for compensating control input based on feedback velocity $\dot{\theta}$, where with a hyperplane matrix S as $[S_2 \quad S_3]$, a switching function σ in the sliding mode controller contains $S \cdot x$.

[0016]   The sliding mode controller is preferably input with command velocity $\dot{r}$ and command acceleration $\ddot{r}$, and with C_{ff} and A_{ff} as gain. The switching function σ is expressed in Equation (11).

$$\sigma = S \cdot x + C_{ff} \cdot r + A_{ff} \cdot \dot{r} \qquad (11)$$

Control input u is the sum of linear control input u_l and non-linear control input u_{nl}, where the linear control input u_l is expressed in Equation (12):

$$u_l = -(S \cdot B)^{-1}(S \cdot A \cdot x + C_{ff} \cdot \dot{r} + A_{ff} \cdot \ddot{r}) \qquad (12)$$

$$A = \begin{bmatrix} 1 & 0 \\ 0 & 0 \end{bmatrix}, B = \begin{bmatrix} 0 \\ Kt/J \end{bmatrix}, C = \begin{bmatrix} 1 & 0 \end{bmatrix}, u = Iq$$

[0017]   In a second aspect, the present invention is a position control device for causing a position of a control system, including a servomotor and a moving body driven by the servomotor, to track a command value. The position control device comprises a sliding mode controller for receiving command position r and state variable x of the control system and providing a control input u to the servomotor without using integrating elements, wherein state variable x is expressed in

Equation (10), wherein θ is feedback position and $\dot{\theta}$ is feedback velocity. The position control device further includes a disturbance variable compensator for compensating control input u based on feedback velocity $\dot{\theta}$.

[0018]   This brief summary has been provided so that the nature of the invention may be understood quickly. A more complete understanding of the invention can be obtained by reference to the following detailed description of the preferred embodiments thereof in connection with the attached drawings. It is to be understood that other embodiments may be utilized and changes may be made without departing from the scope of the present invention.

BRIEF DESCRIPTION OF THE DRAWINGS

[0019]   Figure 1 is a block diagram of a conventional position control device;

[0020]   Figure 2 is a block diagram of one example of a position control device according to the present invention;

[0021]   Figures 3A & 3B are graphs illustrating plotting tracking error and step response, using the Figure 2 position control device; and

[0022]   Figures 4A & 4B are graphs illustrating plotting tracking error and step response, using the conventional position control device depicted in Figure 1.

DETAILED DESCRIPTION OF THE INVENTION

[0023]   Figure 2 illustrates one example of a position control device according to the present invention. The position control device includes a sliding mode controller for supplying control input u to a control system, a disturbance variable

compensator for compensating control input u in response to a disturbance, and a state observer for observing state variable x.

[0024] Sliding mode controller 260 does not include any integrating elements. Within the sliding mode controller 260, an integral value of an error between command position r and feedback position y is not supplied to a switching function. A disturbance variable compensator 220 compensates with the entire error as disturbance. The switching function is expressed as follows.

$$\overline{\sigma} = \overline{S} \cdot x \tag{13}$$

$$\overline{S} = [S_2 \quad S_3], x = \begin{bmatrix} \theta \\ \dot{\theta} \end{bmatrix}$$

[0025] The switching function and hyperplane matrix in Equation (13) are represented using $\overline{\sigma}$ and $\overline{S}$ in order to differentiate them from those in Equation (4). State observer 230 receives a feedback position y and control input u as inputs, and supplies state variable x to the sliding mode controller 260. The state variable x is multiplied by a hyperplane matrix $\overline{S}$ using multiplier 284.

[0026] Design of sliding mode controller 260 is also governed by the Equation (5). The linear and non-linear control inputs are respectively expressed by Equations (14) and (15).

$$\overline{u}_l = -(\overline{S} \cdot B)^{-1}(\overline{S} \cdot A \cdot x) \tag{14}$$

$$\overline{u}_{nl} = -k(\overline{S} \cdot B)^{-1} \frac{\overline{\sigma}}{|\overline{\sigma}| + \eta} \tag{15}$$

The linear and non-linear control inputs of Equations (14) and (15) are represented using $\overline{u}_l$ and $\overline{u}_{nl}$ in order to differentiate them from those in Equations (6) and (7). To increase tracking during movement using feedforward compensation of velocity

and acceleration, Equations (13) and (14) are expressed by Equations (16) and (17), respectively.

$$\bar{\sigma} = \bar{S} \cdot x + C_{ff} \cdot r + A_{ff} \cdot \dot{r} \tag{16}$$

$$\bar{u}_l = -(\bar{S} \cdot B)^{-1}(\bar{S} \cdot A \cdot x + C_{ff} \cdot \dot{r} + A_{ff} \cdot \ddot{r}) \tag{17}$$

[0027] Command position r from a numerical control device (not shown) is supplied to block **262**. Command velocity $\dot{r}$ is sent to feedforward compensator **252** and feedforward compensator **261**, and command acceleration $\ddot{r}$ is sent to feedforward compensator **251**. Output $\bar{S} \cdot x$ of multiplier **284**, and the outputs of feedforward compensator **261** and feedforward compensator **262** are supplied to adder **285**, and a switching function $\bar{\sigma}$ is sent from adder **285** to smoothing function **286**. Block **287** is input with the smoothing function **286** output, and block **287** sends a non-linear control input $\bar{u}_{nl}$ to adder **288** based on Equation (15). The output of feedforward compensator **251** and feedforward compensator **252** are respectively transmitted to block **263** and block **264**, and state variable x is sent to block **268**. Linear control input $\bar{u}_l$ is obtained from outputs of block **263**, block **264**, and block **268** based on Equation (17). Adder **288** generates a control input u, namely q axis current Iq, as an output of sliding mode controller **260**. Sliding mode controller **260** restrains the state of control system **210** on a switching hyperplane by switching of control input u.

[0028] Control input u, namely q axis current Iq, and feedback velocity are supplied to disturbance variable compensator **220**, and disturbance variable compensator **220** compensates control output u in response to disturbance torque. Q axis current Iq is multiplied by torque constant Kt in multiplier **221**. A feedback velocity is a measured velocity $\dot{\theta}$, or an estimated velocity is output from a suitable

state observer. A differentiator **245** for differentiating measured position θ outputs

measured velocity $\dot{\theta}$, and this measured velocity $\dot{\theta}$ is multiplied by $\frac{J}{T}$ inside

multiplier **222** and multiplier **224**, where T represents a time constant of the low

pass filter **223**. The sum of the outputs of the multiplier **221** and multiplier **222** is

supplied to the low pass filter 223, where s represents a Laplacian operator.

Estimated disturbance torque $\hat{\tau}_L$ is obtained by subtracting the output of multiplier

224 from the output of the low pass filter **223**. Multiplier **225** multiplies estimated

disturbance torque $\hat{\tau}_L$ by $\frac{1}{Kt}$, and generates estimated disturbance $\hat{d}$ having

estimated disturbance torque $\hat{\tau}_L$ converted to q axis current. Adder **226** supplies a

sum of control output u and estimated disturbance $\hat{d}$ to control system **210**.

[0029] As shown in Figure 3A, gains in the position control device of Figure 2

have been adjusted so that maximum tracking error is less than 10 counts, and the

graph of Figure 3B shows step response measured in such a state.

[0030] As shown in Figure 4A, gains in the position control device of Figure 1

also have been adjusted so that maximum tracking error is less than 10 counts. The

graph of Figure 4B shows step response measured in this state, indicating an

undesirable overshoot. As shown in Figure 3B, the position control device of the

present invention can prevent the occurrence of overshoot in a state where tracking

error is small.

[0031] The invention has been described with particular illustrative

embodiments. It is to be understood that the invention is not limited to the above-

described embodiments and that various changes and modifications may be made by

those of ordinary skill in the art without departing from the spirit and scope of the

invention.